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Body composition and skin temperature variation

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FRIM, J., S. D. LIVINGSTONE, L. D. REED, R. W. NOLAN, AND R. E. LIMMER. *Body composition and skin temperature variation.* J. Appl. Physiol. 68(2): 540–543, 1990.—Temperature variations near four common torso skin temperature sites were measured on 17 lightly clad subjects exposed to ambient temperatures of 28, 23, and 18°C. Although variations in skin temperature exceeding 7°C over a distance of 5 cm were observed on individuals, the mean magnitude of these variations was 2–3°C under the coolest condition and less at the warmer temperatures. There was no correlation between the temperature variation and skinfold thickness at a site or with estimations of whole body fat content. These findings imply that errors in mean skin temperature measurement could arise from probe mislocation and/or subcutaneous fat distribution and that the problem becomes more acute with increasing cold stress. However, the magnitudes of these errors cannot be easily predicted from common anthropometric measurements.

skinfold thickness; body fat; cold stress; temperature measurement error

IT IS WELL KNOWN that subcutaneous fat is a good insulator relative to other tissues and that skin overlying such fat deposits tends to cool more than adjacent skin during cold exposure (9). It is also well established that subcutaneous fat is distributed nonuniformly over the body, particularly on the torso (4). One would surmise, then, that a slight shift in the placement of a skin temperature probe might lead to variations in skin temperature measurements, particularly if the site is on an area of nonuniformly distributed fat.

Recent studies have in fact shown that skin temperature can vary by as much as 8°C over a lateral distance of only 2.5 cm during exposure to severe cold (6). Because mean skin temperature is commonly used as an indicator of thermal stress in studies of the effects of adverse environments on humans, it is important to know the extent of this variation and the potential error it may cause in determining mean skin temperature. It would further be helpful to know if and how this variation relates to body composition and environmental stress.

The present study was undertaken to examine the relationships among body composition, skinfold thickness, and skin surface temperature variations. Thermistors were used to measure skin temperatures at four standard torso sites, and skinfold thicknesses were measured at these same sites. Subjects were selected to provide a sample with a wide range of body fat content, and the experiment was carried out at three different ambient temperatures to determine the effect of environmental conditions on the observed relationships.

METHODS

Seventeen male volunteers gave their informed consent to participate as subjects in this study. Skinfold thicknesses and skin temperatures were measured at four regions of the torso: the abdomen, chest, upper back, and lower back. These regions were chosen for the following reasons: *1*) they correspond to the four torso sites that are part of an established 12-point skin temperature measurement system (8); *2*) at least one of these sites is part of most other skin temperature measurement systems (7, 10); and *3*) the torso is a region where one sees great variations in subcutaneous fat deposits between subjects of various statures (4).

Skinfold thicknesses at each torso site were measured to the nearest 0.1 mm by using Harpenden calipers with the subject standing and relaxed. Three readings were taken at each site, and the mean of the two closest readings was recorded as the skinfold thickness for that site. All skinfold measurements were carried out by the same person by using standard methods (1). In addition, skinfold measurements were taken at the biceps, triceps, subscapular, and suprailiac sites, and overall body composition was expressed both as the sum of these four skinfolds and as percent body fat by using the age-specific formulas of Durnin and Womersley (3).

Temperatures were measured with type 44004 thermistors (Yellow Springs Instrument) attached to the skin with one layer of nonporous Blenderm (3M) surgical tape. One thermistor, designated M for middle, was placed directly on each of the four torso sites. The M thermistor at the chest site was positioned on the left side of the front of the torso at a point 2.5 cm above and 2.5 cm to the right of the nipple and the M thermistor at the abdominal site was placed at a point 2.5 cm above and 2.5 cm to the left of the navel. The M thermistors at the back of the torso were placed at corresponding positions on the upper and lower back sites. Surrounding each M thermistor at a radius of 5 cm were four thermistors placed as the points on a compass and designated N, S, E, and W. This thermistor arrangement is shown in Fig. 1 and was used to measure the variation in temperature in the immediate vicinity of each torso site. Thermistor locations were marked on each subject with indelible ink to ensure reproducible thermistor placement between exposures.

After attachment of the thermistors to the body, the

subjects, wearing only a pair of loose fitting shorts, rested quietly in a temperature-controlled room. The air temperature of the room was set at either 28, 23, or 18°C, and all subjects were exposed to all three conditions on 3 consecutive days. The same order of exposure from warm to cold was used for all subjects.

A pilot study showed that 60 min was sufficient time for skin temperatures to reach a steady state in even the coolest test environment. During the first 45 min of the exposure period, the subject sat on a wooden chair facing the chair back with arms resting on the chairback; during the final 15 min he stood with his arms resting on supports that kept the arms well away from the body. These postures were selected to minimize the influence of arm contact on torso skin temperatures. At the end of the 60-min exposure, the temperature of each thermistor was measured by an automated data acquisition system (Hewlett-Packard 3497A Data Acquisition/Control Unit and HP 85 Computer) and stored on disk for later analysis.

The variation in skin surface temperature in the immediate vicinity of a standard measurement site was assessed by using three separate variables derived from the thermistor data. Variance was defined as the statistical variance of skin temperature calculated from the cluster of five thermistors located at each torso site. Range was defined as the difference between the warmest and coolest of the five thermistor probes at a torso site. Difference was defined as the magnitude of the greatest temperature difference between the M thermistor and any of the remaining four thermistors.

These three temperature variation variables were determined for each site on each subject under each of the three environmental temperatures. Correlation coefficients were calculated between these variables and skinfold thickness at each site, and with the two measures of overall body composition. Between-site and within-site differences in these variables at each ambient condition were evaluated by using Student's paired t tests. Results were considered statistically significant if $P \leq 0.05$.

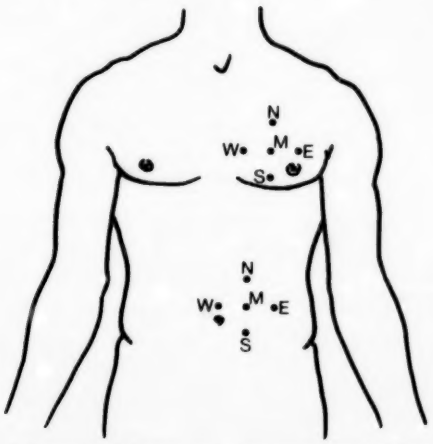

FIG. 1. Schematic of thermistor arrangement used to measure temperature variation in immediate vicinity of a standard torso skin temperature measurement site. M thermistor was placed directly on the site, whereas N, S, E, and W thermistors were spaced 5 cm radially from M thermistor. A similar arrangement was used on upper and lower back sites.

RESULTS

The physical characteristics of the subjects used in this study are presented in Tables 1 and 2. It can be seen that the anthropometric measurements and body compositions of the 17 subjects covered a broad range.

Figure 2 shows the relationship between mean skin temperature and skinfold thickness at each of the four sites. It can be seen that the mean temperature decreased with increasing skinfold thickness. This relationship was significant at the abdomen ($P < 0.01$ at 18°C and $P < 0.05$ at 28°C) and at the lower back ($P < 0.01$ at 18°C and $P < 0.05$ at 28°C) but not at the other two sites.

The means of the statistical variances (variable Variance) used to estimate the variations in skin temperature at each standard torso site are shown in Table 3. It can

TABLE 1. *Physical characteristics of subjects*

Subj No.	Age, yr	Height, cm	Weight, kg	SUM-4, mm	%BF
1	25	173.0	64.3	32.1	13.5
2	25	178.0	74.1	37.9	15.5
3	21	177.5	71.6	39.7	16.1
4	27	170.5	70.4	39.8	16.1
5	30	175.0	80.3	47.6	21.0
6	38	163.0	70.6	61.9	23.8
7	35	171.0	106.1	73.7	25.7
8	47	178.0	78.1	55.0	25.9
9	44	189.5	87.5	55.8	26.1
10	42	174.0	79.0	59.1	26.9
11	35	177.0	101.5	84.7	27.2
12	40	171.5	71.5	62.0	27.6
13	41	173.5	93.1	71.1	29.5
14	56	174.5	82.0	61.4	29.6
15	46	176.0	82.3	71.6	29.6
16	45	175.0	100.8	93.6	33.4
17	40	183.5	124.5	111.8	36.0

SUM-4, sum of 4 skinfolds measured at the biceps, triceps, subscapular, and suprailiac sites; %BF, percent body fat calculated with age-specific formulas of Durnin and Womersley (3). Subjects are listed in order of increasing %BF.

TABLE 2. *Torso skinfold thicknesses of subjects*

Subj No.	Skinfold Thickness, mm			
	AB	CH	UB	LB
1	11.2	6.7	10.1	12.1
2	9.9	10.2	10.5	11.4
3	14.1	13.1	10.5	12.2
4	13.2	7.1	11.5	16.3
5	9.4	5.8	15.6	13.3
6	32.5	28.3	16.8	14.8
7	35.3	30.5	17.5	36.4
8	23.0	19.3	16.8	23.2
9	23.2	23.6	13.7	18.9
10	18.9	15.8	15.9	15.8
11	29.0	21.7	22.5	27.9
12	16.9	19.0	16.6	13.3
13	30.4	23.3	24.2	24.3
14	34.6	17.8	16.4	20.1
15	18.8	18.4	21.0	22.6
16	33.9	31.1	25.7	31.0
17	37.7	32.0	35.8	32.6

AB, abdomen; CH, chest; UB, upper back; LB, lower back.

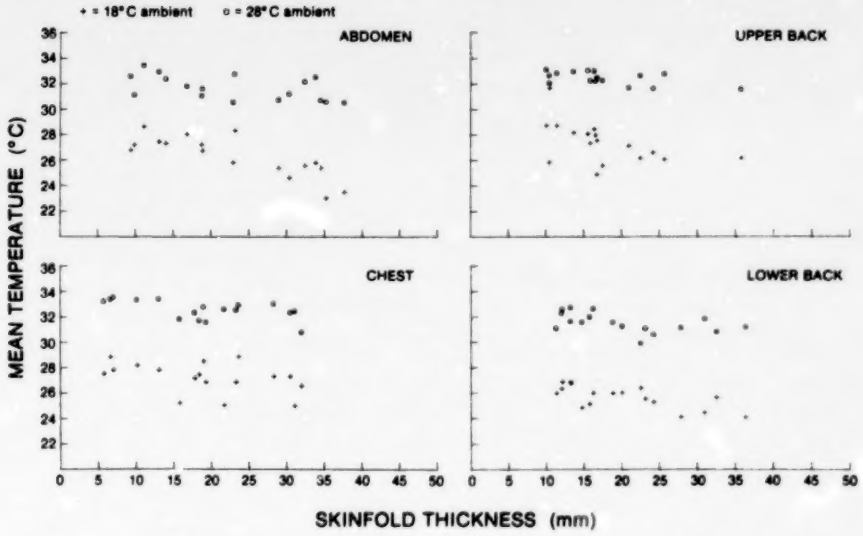

FIG. 2. Plot of mean skin temperature vs. skinfold thickness at each of 4 sites for ambient temperatures of 18 and 28°C. Values at 23°C ambient temperature lay between these values and are omitted for clarity.

TABLE 3. *Variable: variance (statistical variance of skin temperature at each site)*

Site	Ambient Temperature, °C		
	28	23	18
AB	0.38	1.14	1.48*
CH	0.39*	0.91	1.47*
UB	0.30	0.72	1.10*
LB	0.38	1.05	1.57

Data are means for 17 subjects in $°C^2$. * n = 16. See Table 2 for abbreviations.

TABLE 4. *Variable: range (difference between warmest and coolest temperature at each site)*

Site	Ambient Temperature, °C		
	28	23	18
AB	1.44	2.50	2.65*
CH	1.44*	2.10	2.62*
UB	1.29	2.03	2.48*
LB	1.50	2.37	2.86

Data are means for 17 subjects in °C. * n = 16. See Table 2 for abbreviations.

TABLE 5. *Variable: difference (greatest difference between middle and other temperatures at each site)*

Site	Ambient Temperature, °C		
	28	23	18
AB	1.07	1.84	1.81*
CH	1.10*	1.66	2.23*
UB	1.11	1.51	2.06*
LB	1.04	1.93	2.14

Data are means for 17 subjects in °C. * n = 16. See Table 2 for abbreviations.

TABLE 6. *Correlation of variable variance and torso site skinfold thickness*

Site	Ambient Temperature, °C		
	28	23	18
AB	0.436	0.495*	0.404†
CH	0.034†	0.168	−0.319†
UB	0.296	−0.062	−0.129†
LB	−0.016	0.008	−0.549*

Data are correlation coefficients for 17 subjects in °C. * Statistically significant ($P \leq 0.05$); † n = 16. See Table 2 for abbreviations.

be seen that for each site the magnitude of the skin temperature variation increased as the ambient temperature decreased. The smallest variance was at the upper back site for all three temperature conditions, although values of variance for the remaining three sites were larger but similar to each other. No order trend among these three sites was indicated.

Tables 4 and 5 show similar data for range and difference, respectively. As with variance, both of these variables indicated an increased variation in temperature at each torso site as the environmental temperature decreased.

Student's paired t test was used to examine the differences in temperature variations between sites at each ambient condition. In general, with the exception of only a few cases, there were no significant differences in the mean variations between sites at any ambient condition regardless of which temperature variation variable was used. This suggests that similar temperature variations can be expected at the four torso sites of any one subject.

Paired t tests were also used to examine the differences in temperature variations at each site between conditions. All three variables showed highly significant differences at each site between ambient temperatures of 28 and 23°C, but not between 23 and 18°C.

The data presented in Tables 3–5 are mean values over the 17 subjects treated as a single group, but they give no indication of the range of values obtained in this study. However, the largest variance value was $8.3°C^2$, whereas the largest range and difference were both 7.2°C. All these values were obtained from the chest site of *subject 4* during the 18°C exposure.

To determine whether any relationship existed between the magnitude of the temperature variation at a site and local body composition, correlation coefficients were calculated between the three variables (variance, range, and difference) and the skinfold thickness at each site under each environmental condition. The results for variable variance are shown in Table 6. Although two of the correlations were statistically significant, no correlation coefficient exceeded a value of $r \geq 0.7$, suggesting little practical significance to the relationships (11). Similar results (not shown) were obtained for the variables range and difference.

Similarly, the correlations between the three temperature variation variables and the measures of overall body composition as sum of the four skinfolds and percent body fat were no greater than $r = 0.49$, , which was the only statistically significant correlation.

Finally, as a check for second order effects, differences in the magnitudes of each of the three variables between 28 and 23°C and between 23 and 18°C were calculated, and these were examined for correlation with local torso skinfold thickness at each site. As before, generally poor correlations were obtained, and no pattern was visible in the data.

DISCUSSION

The present results show that temperature variations near standard torso skin temperature measurement sites increase as the ambient temperature decreases. These findings are consistent with those of LeBlanc (9) and the more recent work of Frim and Livingstone (6) that showed that subcutaneous fat deposits allow the overlying skin to cool more than adjacent areas with less fat. In fact, the magnitude of the largest variation found in the present study with the use of nearly nude subjects exposed to mild cold (range or difference = 7.2°C) is very similar to the 8°C difference seen on the suprailiac site in a previous study with the use of heavily clothed subjects exposed to severe cold (6). It appears, therefore, that variations in temperature of this magnitude can occur near a standard torso site under widely different experimental conditions. These results also indicate that thermistor placement becomes more critical as the environmental cold stress increases.

The increases in the magnitudes of the torso site temperature variations as ambient temperatures dropped were probably a consequence of cutaneous vasoconstriction. The fact that there were significant increases in the temperature variations between the 28 and 23°C exposures, but not between the 23 and 18°C exposures, suggests that vasoconstriction was already maximal near 23°C. This is consistent with the accepted critical air temperature of 25–27°C for an unclothed man (5).

The observation that temperature variations at torso sites are not correlated with common measures of overall body composition is not surprising, because such comparisons involve unrelated parts of the body. However, the finding that there is little correlation with skinfold thickness at a given site was somewhat unexpected. Our study shows that the magnitude of the temperature variation near a torso site cannot be accurately estimated from the measurement of skinfold thickness at that site. We therefore speculate that the shape and size, rather than the thickness of the fat pads, are the important characteristics causing the variations in temperature. A standard measurement of skinfold thickness does not adequately describe these relevant fat pad characteristics.

Although fat deposits do influence the variation of skin temperature in an individual, perhaps only a minimum amount of fat is needed to provide near maximum variation. This conclusion is supported by the finding that there was no significant difference in temperature variations between sites. Thus a subject with at least a critical fat thickness at one site probably has critical fat thicknesses at all areas of the torso that were examined. The anthropometric data in Table 2 support this hypothesis.

In summary, it was found that in some instances there is significant relationship between mean skin temperature and skinfold thickness. More importantly, this study has also shown that temperature variations do exist in the immediate vicinity of standard torso measurement sites and that these variations can be up to 7°C between individuals under identical environmental conditions. The local temperature variations increase in magnitude with increasing severity of cold stress but bear no direct relationship to skinfold thickness at the corresponding site or to measures of overall body composition.

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